Coastal change since 1950 in the southeast Chukchi Sea, Alaska, based on GIS and Field Measurements.

William F. **Manley**, [1] Owen K. **Mason**, [1,4] James W **Jordan**,[2] Leanne R. **Lestak**,[1] Diane M. **Sanzone**,[3] and Eric G. **Parrish** [1]

[1] **Institute of Arctic and Alpine Research** (INSTAAR), University of Colorado, Boulder, CO 80309-0450; ***Contact***: <William.Manley@colorado.edu>

[2] **Antioch University New England**, Department of Environmental Studies, Keene, NH 03431.

[3] **Arctic Inventory and Monitoring Program, National Park Service,** Fairbanks, AK 99709; present: **British Petroleum**, 900 E. Benson Blvd., Anchorage, AK 99509-4254.

[4] **Geoarch Alaska**, P.O. Box 91554, Anchorage, AK 99509; ***Contact***: <geoarch@ptialaska.net>

ABSTRACT. Coastal environments at high latitudes are experiencing rapid change. Coastal erosion threatens a variety of near shore marine, terrestrial, and freshwater habitats, and may be accelerating with Arctic warming. To better understand impacts for national parks in northwestern Alaska, a collaborative study has begun to document coastal change in the southeast Chukchi Sea. A field-based component includes: repeat photography; mapping and description of sediments and landforms; and periodic ground-truth measurements of shoreline change since 1987 at 27 coastal monitoring sites. A geospatial component began with creation of digital orthoimagery over a large area (>6000 km^2) at high resolution (1.0 m or better) for three "time slices": approx. 1950, approx. 1980, and 2003. Spatial analysis of bluff retreat was then conducted for selected areas near the monitoring sites using the USGS DSAS extension to ArcGIS. Results indicate that the GIS-based measurements have acceptably low errors (±0.1 m/yr or better). Transects with 20-m spacing reveal high spatial variability related to coastal morphologies and processes. A comparison of the two time intervals suggests temporal variability also. For example, bluff erosion rates appear to have decreased after 1980 for the north-facing coast of Bering Land Bridge National Park (BELA) while increasing after 1980 for the west-facing coast of Cape Krusenstern National Monument (CAKR). In general, most of the >600-km-long coast from Wales to Kivalina has experienced erosion in the past five decades, with long-term average rates of 0 to -3 m/yr. Direct impacts include beach and bluff retreat, overwash deposition, migration or closure of inlets and lagoons, capture of thaw-lake basins, and release of sediment and organic carbon to nearshore waters. Higher temporal resolution is needed, but the coastal ecosystems in the region appear to be sensitive to: the frequency and intensity of storm events, increasing temperatures, permafrost melting, sea-level rise, and increasing length of the summer ice-free season.

Study Area

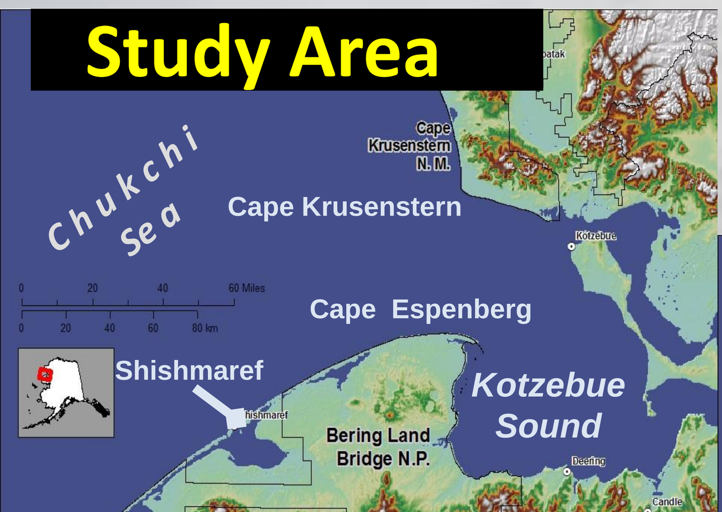
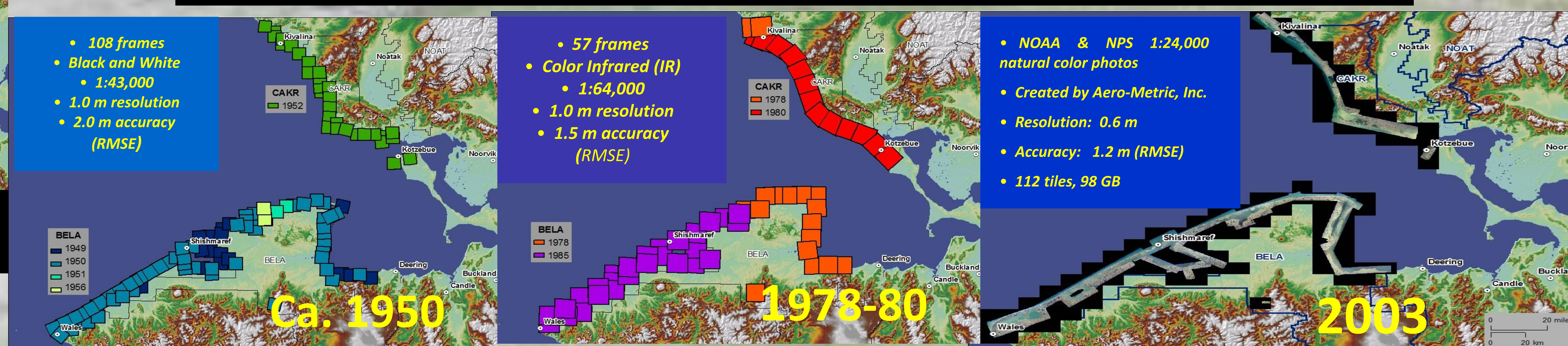


Figure 1. Northwest Alaska (cf. Hameedi & Naidu 1988 for background descriptions on the microtidal, (50-70 cm), wave-dominated sea.

Aerial Photograph Data base: Three Time Slices, ca. 1950, 1980 and 2003 (Figs. 4a, b & c, below)



Field Methods

Figures 2a-2c. Measurement techniques.

To ground-truth the photogrammetric data sets, the project included field visits by helicopter to re-measure stations established by James Jordan in 1987 and 1988, re-visited intermittently in the 1990s, with the support of the National Park Service. Each station consisted of two rebar stakes placed perpendicular to the shore at 20 and 40 m from the bluff or dune erosion scarp. The revisit in 2006 produced distance measurements and fairly accurate GPS coordinates to identify the station. About 80% of the stations could be relocated.

Shoreline Reference Feature (SRF): the "bluff top" (wave-cut scarp). Figs. 3a-3d

Fig. 3 a.

Fig. 3 c.

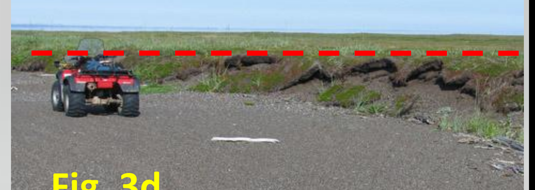


Fig. 3d

Fig. 3b

Figures 3a, b, c and d. The coast consists of several principal landforms: Sandy barrier Islands and spits, south of Shishmaref, (Figs. 3a, c) with gravelly islands north and south of Cape Krusenstern Distinguishing the erosional scarp is a critical part of the interpretative process, as marked by the dashed red line. Mainland bluffs are comparatively rare, restricted to several tens of km west of Cape Espenberg (Fig. 3b) and north and south of the Cape Krusenstern beach ridges. Gravel beach ridges occur at Cape Krusenstern (Fig. 3d) and Sisualik spit.

Photographic Interpretation Methodology

Before documentation of historical shoreline movement can be accomplished a shoreline proxy must be defined. This feature must be repeatable over time (Boak and Turner 2005). For Cape Krusenstern National Monument (CAKR) and Bering Land Bridge National Preserve (BELA) the bluff top landward edge (Boak and Turner, 2005, Moore and Griggs, 2002) was digitized in ArcGIS using stream mode.

We used the U.S. Geological Survey Open-file Report 2005-1304 DSAS software package (http://woodshole.er.usgs.gov/project-pages/dsas/version3/index.html) to calculate shoreline change. Once all shorelines were digitized, a baseline was created that mirrored the general shape of the shoreline and is offset approximately 150 – 250 meters landward from the bluff top. According to the DSAS manual (Thieler et. al. 2005): "The DSAS extension generates transects that are cast perpendicular to the baseline at a user-specified spacing alongshore. The transect/shoreline intersections are used by the program to calculate the rate-of-change statistics." Transects were cast perpendicular to the baseline and spaced 10 meters apart for the entire length of the baseline, each linked to tables containing a series of shoreline change statistics and distance measurements. The same transects were recast three times to compute coastal change for different time periods. In each case the change between just two time periods was calculated. For this analysis the end-point rate (EPR) statistic was utilized. The EPR statistic is of the measured distance between two shorelines divided by the time elapsed between the two shoreline dates. The final EPR value is the yearly rate of change (positive or negative) for a given time period. For this study, all EPR units are meters per year.

Error analysis

For this project, measurement errors are related to geocorrection of aerial photos and onscreen digitization a simple calculation of the shoreline feature. Calculating shoreline position errors: A single yearly shoreline position error can be calculated by taking the square root of the sum of the squares (Morton et. al. 2004 and Fletcher et. al. 2003) of geocorrection error (g) and bluff top digitization error (bt) for each year. Thus, the position error for a given year for the bluff top is shown in Equation 1: $E_{year} = \pm \sqrt{g^2 + bt^2}$ Then errors are calculated for each time period (early, late or long term) by taking the square root of the sum of the squares of the two bracketing yearly error values and annualizing over the time period of interest. The "early" time period calculation is shown in Equation 2: $E_{year} = \pm \sqrt{E_{1950s}^2 + E_{1980s}^2}$. This error value then can be applied to any given transect. The annualized error value for the "Early" period (ca. 1950 – ca. 1980) is ± 0.20 m, "Late" period (ca. 1980 – 2003) is ± 0.23 m and for the "Long Term" time period (ca. 1950 – 2003) is ± 0.09 m. The signal to noise ratio is very good: the error values (noise) are substantially less than the annualized shoreline change rates (signal), particularly for the "Long term" rates.

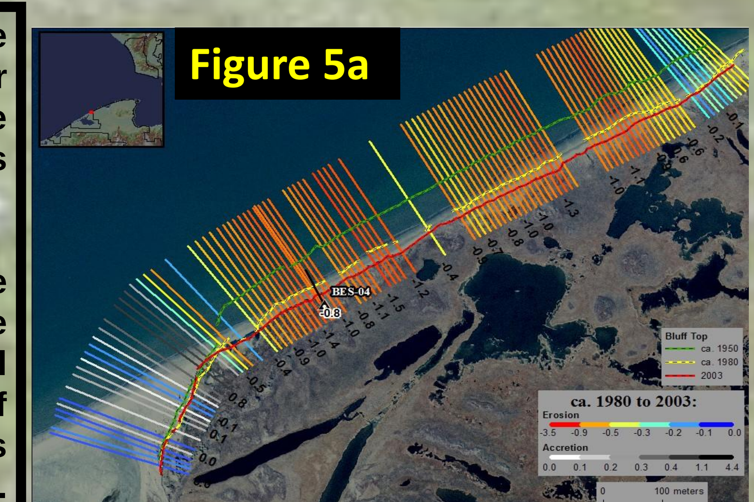


Figure 5a

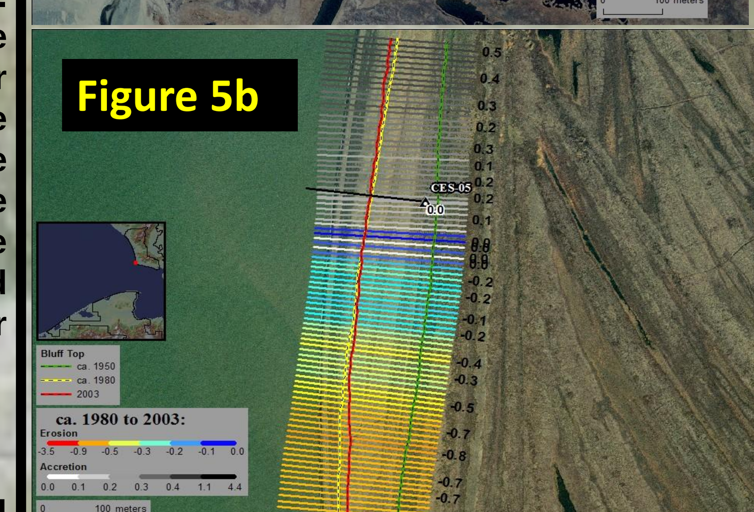


Figure 5b

Photogrammetric techniques produced several thousand measurements across the two coastlines. The images show that erosion prevailed along much of the exposed shore on the south coast (Fig. 5a, above), although accretion occurred within storm surge channels and with both accretion and erosion within several km on the northern coast near Cape Krusenstern (Figure 5b, above, lower). The past locations of the shore SRF are indicated by green (1950), yellow (1980s) and red (2003) lines. Gaps are related to the adequacy of identifying Shoreline Reference Features.

Results: Uneven Erosion Rates North vs. South facing coasts, Increases after 1980 in the North, Decreases in the South

Coastal Reach	Time Period	Average Erosion (m) ± SD	Time Period	Average Erosion (m) ± SD
North (CAKR)	1950s-1980s	0.0 ± 1.1	1980s-2003	-0.5 ± 0.6
South (BELA)	1950s-1980s	-0.6± 0.4	1980s-2003	-0.2 ± 0.3

"Early" Period ca. 1950-1980

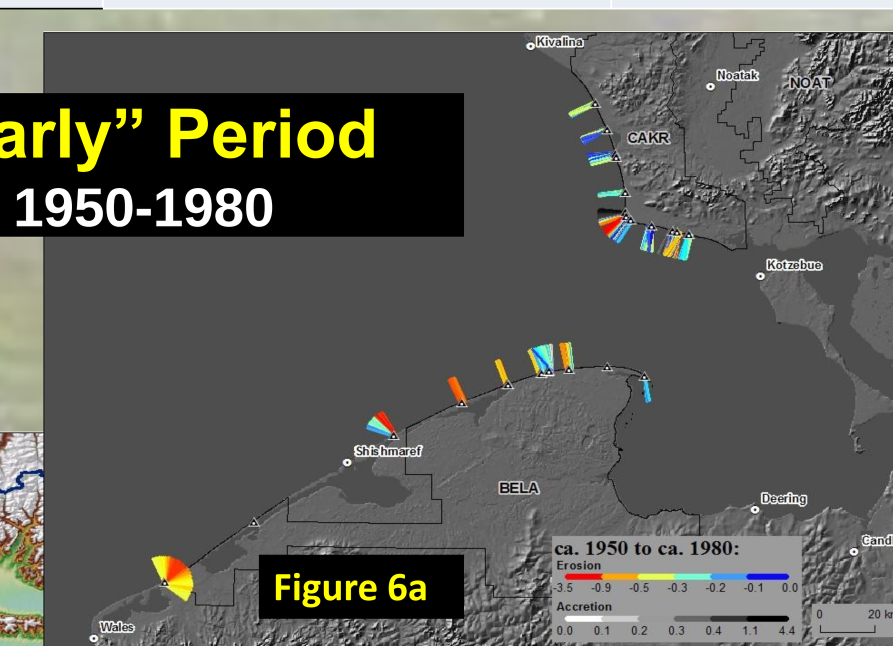


Figure 6a

"Late" Period ca. 1980 – 2003

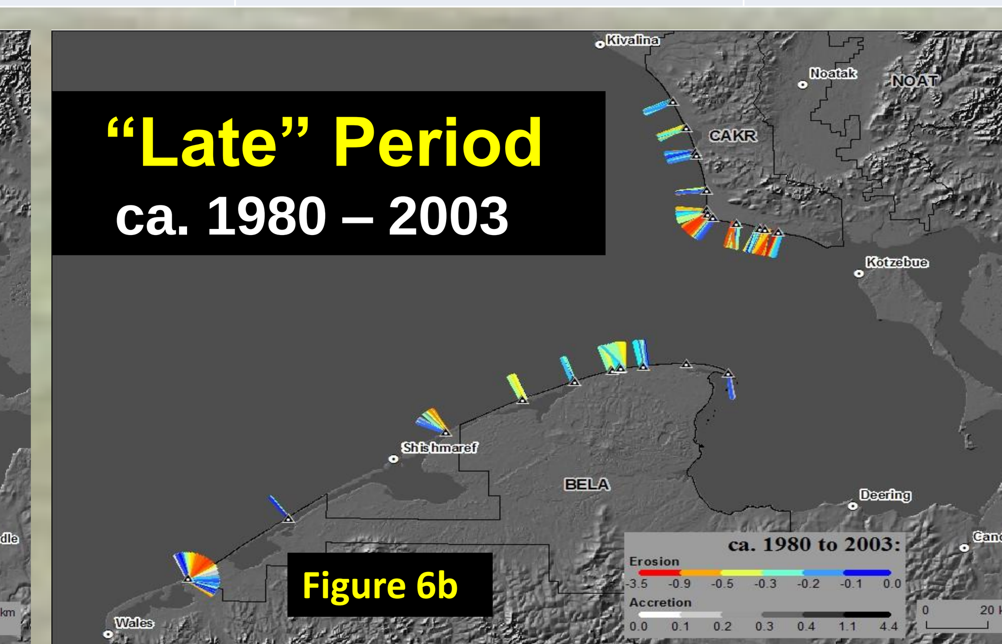


Figure 6b

Explanations: Storm Climatology

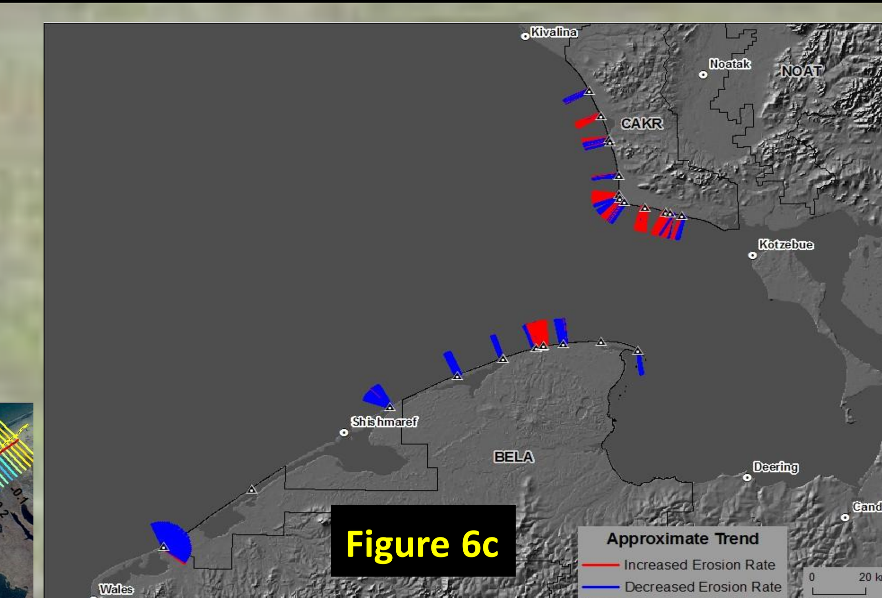


Figure 6c

Coastal erosion is controlled by the passage of storm tracks across the Chukchi Sea; the persistence and direction produces winds of variable strength that foster waves and water levels that undercut soft sediments. The largest storms to impact the study area occurred in the 1950s to 1970s (Wise et al. 1981); the "great storm of 1974" (Fathauer 1975) entered from the Bering Sea and recorded >4 m high waves at Shishmaref. This storm accounts for most of the erosion on the south coast (Fig. 6a). Since 1980, storm direction has shifted to impact the north coast (Figs. 6b,c), the impact of melting permafrost is local.

And the developed coast at Shishmaref?

July 1992

August 2006

Figures 7a and 7b (left). View southwest in Shishmaref, toward School housing (blue) in 1992 and in Aug. 2006, showing failed revetments in the surf and boulder facing placed in 2005 (Mason 2006). The building (circled) has not been relocated.

Figures 8a, b and c. Aerial photographs of Sarichef Island in 1949, 1980 and 2003. Preliminary calculations are that erosion rates average 1 m per year, contrary to the anecdotal accounts of >10 m per year reported by news agencies since 1997 (Lempinen 2006). The average rate is twice the rate on undeveloped adjacent islands. Erosion has accelerated around the margins of the revetments, expanded from cement blocks and gabions in the 1980s to boulders placed since 2001 .

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